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Variation in Aluminum Tolerance Among Six Genera of Trees

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Abstract. Using a hydroponic system, the relative aluminum tolerance of 11 tree species was evaluated at 10 levels of Al concentration from 0 to 280 ppm. Species evaluated were *Alnus glutinosa*, *Betula alleghaniensis*, *B. papyrifera*, *B. populifolia*, *Elaeagnus umbellata*, *Pinus rigida*, *P. sylvestris*, *P. virginiana*, *Populus* hybrid clone NE-388, *Quercus palustris*, and *Q. rubra*. A comparison of tolerance indices based on root elongation in Al vs. non-Al solutions revealed a wide range of Al tolerance among species. *Populus* hybrid and *E. umbellata* were very sensitive to even low Al concentrations (10–40 ppm), while *A. glutinosa*, *Betula* spp., *Pinus* spp., and *Quercus* spp. were tolerant to much higher concentrations (80–160 ppm). This level of tolerance is greater than that reported for most field crops. Forest Sci. 24:565–568.

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Aluminum toxicity is an important growth-limiting factor for plants on many acidic soils and spoils produced by the surface mining of coal. Ameliorating these troublesome areas with lime treatments is possible but difficult and expensive. An alternative solution is to select or breed aluminum tolerant plants. While inter- and intraspecific genetic variation has been demonstrated in many field crops (see, for example, Wright 1976), little is known about differential aluminum tolerance in woody plants.

The following research was conducted to determine the relative tolerance of tree species to various levels of aluminum in hydroponic culture. Eleven species were selected for study: yellow, gray, and paper birches (*Betula alleghaniensis* Brit., *B. populifolia* Marsh., *B. papyrifera* Marsh.); Virginia, pitch, and Scotch pines (*Pinus virginiana* Mill., *P. rigida* Mill., *P. sylvestris* L.); pin and red oaks (*Quercus palustris* Muenchh., *Q. rubra* L.); European black alder (*Alnus glutinosa* [L.] Gaertn.); autumn-olive (*Elaeagnus umbellata* Thunb.); and a hybrid poplar (*Populus maximowiczii* × *trichocarpa* Schreiner and Stout, clone NE-388). All are among those commonly recommended for revegetating spoils.

Materials and Methods

Seeds of all species were germinated beginning March 9, 1977, in petri dishes containing moist filter paper. At the same time, poplar cuttings were rooted in containers of deionized water. Where possible, each species was represented by a composite seedlot of several provenances in order to minimize any bias from intraspecific genetic variation. After germination, each seedling used in the study

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was transferred to a prefertilized Jiffy-7® peat pellet (Jiffy-Pot, Ltd., Grorud, Norway) suspended above one of 10 waterproof tanks in a perforated sheet of styrofoam. Poplar cuttings were supported by styrofoam collars with approximately half of the stem extending into the tank below. The peat pellets not only provided support for the seedlings but also supplied essential nutrients during testing in aluminum solutions. As the seedlings developed, a portion of the roots eventually emerged from the peat pellets and entered the tanks. While seedlings were becoming established in the system, the tanks were filled with a half-strength Hoagland solution (Hoagland and Arnon 1950). Solutions were continually aerated.

Beginning June 14, the seedlings were exposed to the following generalized sequence of solutions:

(1) 0.004 M calcium nitrate $\{Ca(NO_3)_2 \cdot 4H_2O\}$
(2) half-strength Hoagland solution
(3) 0.004 M calcium nitrate + one of 10 levels of aluminum (0, 10, 20, 40, 80, 120, 160, 200, 240, and 280 ppm Al).

A combination of aluminum chloride $\{AlCl_3 \cdot 6H_2O\}$ and aluminum sulfate $\{Al_2(SO_4)_3 \cdot 18H_2O\}$ was used to avoid excessive levels of either chloride or sulfate. Calcium nitrate was included in the treatment solutions because calcium, which is relatively immobile in the plant, is essential for normal nutrient uptake and cell division. All solutions were maintained at pH 3.8 by the addition of H_2SO_4 or NaOH. Seedlings remained in each of the solutions for 7 days.

Aluminum treatments were not replicated. Thus, the experiment consisted of 10 tanks, each containing 118 liters of nutrient solution. Each species was initially represented in each treatment by 12 trees located at random in the tank. This design permitted statistical comparisons of species' performances at any one level of aluminum, but not statistical comparisons of differences among aluminum treatments.

Root elongation was measured to the nearest 1 mm for each seedling for both the time it was in calcium nitrate and the time it was in calcium nitrate + aluminum. One root per plant was measured, and the same root was used in both time periods. Root elongation in aluminum solution has been a useful measure of aluminum tolerance in field crop studies (Campbell and Lafever 1976). However, because tree species differ in rate of root elongation, it was necessary in this study to devise an index that would remove this source of variation. The following was used:

$$\text{Tolerance Index} = \frac{\text{Root elongation in calcium nitrate + aluminum}}{\text{Root elongation in calcium nitrate}}$$

Because of possible differences among species in the change of growth rate between periods of measurement, indices calculated in the above manner were divided by the "tolerance index" of the appropriate species in the 0 ppm Al treatment (theoretically a value of 1.0) before statistical analysis of the data.

Salt damage and damping-off caused some mortality during early establishment of the seedlings. This was high enough in the pines, oaks, and birches to cause missing values for some species/treatment combinations. However, a preliminary inspection of the results revealed no statistically significant differences in tolerance among the species in each of these genera, and the data were combined over species within genera to strengthen the analyses of variance. Data were thus analyzed separately for each aluminum treatment as one-way analyses of variance with unequal sample sizes.

TABLE 1. Relative tolerances of six taxa of trees at 10 levels of aluminum concentration.

Species or genus	Aluminum concentration (ppm)									
	0	10	20	40	80	120	160	200	240	280
	Tolerance index[1]									
Quercus spp.	1.0	>1	>1	>1	>1	0.9a	>1 a	0.6	0.1	0
Pinus spp.	1.0	1.0	0.9	>1	0.8	0.4b	0.4bc	0.5	0.5	—
Alnus glutinosa	1.0	0.8	0.8	0.8	0.8	0.3bc	0.8ab	0	0.2	0
Betula spp.	1.0	>1	>1	0.9	>1	0.3bc	0.3c	0.1	0.1	0.1
Elaeagnus umbellata	1.0	1.0	—	0	0	0 c	0 c	0	—	0
Populus hybrid	1.0	0	0	0	0	0	0	0	0	0
Probability of real differences among means[2]	—	0.50	0.50	0.90	0.50	0.999	0.999	0.90	0.75	0.50

[1] Tolerance index = root elongation in Al solution/root elongation in non-Al solution. In 120 and 160 ppm columns, means not followed by the same letter are significantly different at the 0.05 level of probability according to *t*-tests of differences between means (*Populus* data excluded).

[2] From analyses of variance for species differences with *Populus* data excluded.

A second, smaller experiment was performed to more precisely test aluminum tolerance of the hybrid poplar. Twenty cuttings were grown in each of eight tanks containing, in the last week of the experiment, calcium nitrate + either 0, 10, 20, 40, 60, 80, 100, or 120 ppm aluminum. To determine if toxicity was being caused by uptake directly through the stem, the cut ends of one half of the stems in each tank were sealed with a 1:2 mixture of paraffin and petroleum jelly prior to rooting. The remaining stems were not sealed. Other conditions and the calculation of tolerance indices were as previously described.

Results and Discussion

There were pronounced differences among species in tolerance to aluminum, especially when comparison was made between the poplar hybrid and all others. Unlike other species, the roots of poplars were visibly damaged by even the lowest concentrations of aluminum. Injury was in the form of a necrotic-like discoloration of the root tips and appeared within a few days after transfer to the aluminum solutions. Measurements revealed a complete inhibition of root elongation in all poplars at all levels of aluminum except the control. This result was confirmed by results of the second experiment involving poplars alone, in which the growth of plants in all solutions containing aluminum was less than 5 percent of growth in control. For both experiments, no significant differences occurred among the mean tolerance indices of poplar cuttings in any solutions containing aluminum. In the second experiment, there were no differences in injury between sealed and unsealed cuttings—indicating that toxicity was not being enhanced by uptake of aluminum through the cut ends of the stems.

The analyses of variance, which did not include the poplar data because of obvious differences, revealed that the other species also varied in sensitivity to aluminum but not so dramatically (Table 1). Variation among species was significant only in the midrange of aluminum concentrations (120 and 160 ppm Al). Above these concentrations, differences among species decreased rapidly as all tolerance indices approached zero. Below these concentrations, tolerance indices were close to 1.0 (except for autumn-olive) and root growth tended to be erratic,

contributing to a high error variance. Values greater than 1.0 in Table 1 were caused by experimental error and possibly an enhancement of growth at low concentrations. Such growth stimulation by small amounts of aluminum has been observed in other species (Foy 1974).

Species differences are suggested when Table 1 is read both horizontally and vertically, although statistical analyses were possible for only the latter kind of comparison. Next to the poplar hybrid, autumn-olive was the least tolerant of aluminum. This species had virtually no root growth at concentrations as low as 40 ppm Al, although the roots did not become discolored like roots of the poplars. At concentrations for which differences were statistically significant (120 and 160 ppm Al), the oaks were most tolerant of aluminum. European black alder and the pines were somewhat less so, and the birches were intermediate between these species and autumn-olive. Interestingly, however, the pines seemed to retain a moderate degree of tolerance even at 240 ppm Al, a concentration at which the root elongation of other species was almost completely inhibited.

Conclusions

Results of these experiments indicate that seedlings of different tree species vary greatly in tolerance to aluminum toxicity. Hybrid poplars of one clone were sensitive to concentrations as low at 10 ppm Al. Autumn-olive was intermediate in sensitivity, while species of oak, birch, and pine were relatively tolerant of concentrations as high as 80 to 120 ppm Al. This indicates that at least some tree species are tolerant of much higher aluminum concentrations than many agronomic crops that have been tested in a similar manner (Wright 1976) and that are now being recommended for revegetating mine spoils of varying toxicity. Although these results were obtained in hydroponic culture, it is probable that they are indicative of relative performance in soil culture with high concentrations of dissolved aluminum. In other experiments now in progress, we are evaluating the amount of intraspecific variation in some of these species in tolerance to aluminum.

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